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(54) Title: PUTTER-HEADS

(57) Abstract: A putter-head (1) has its centre of mass (15) spaced p mm behind its impact-face (8) at a height h_c mm above the head-bottom (9), a loft angle α_{12} at height 12 mm above the head-bottom (9), a moment of inertia I kg-mm^2 about the vertical axis through the centre of mass (15), a mass M kg and a radius of gyration of K mm about the heel-toe axis (2-10) of the head through the centre of mass (15), where p/I is not more than 0.18, h_c is less than [12 p x sin($_{12}$)], and a parameter $G = [p + (3.2 + 70 x M) x K^2/p]$ is less than 350. The ratio d_2K is less than 1.0, d_2 mm being the vertical offset above the heel-toe axis (2-10) of the axis of attachment of the putter-shaft (3) to the putter-head (1); the attachment-axis of the shaft may be spaced by no more than the shaft-radius from the centre of mass. The impact-face (36) may have an upper flat section (38) that merges smoothly into a cylindrical lower section (39), and the head (30) may be constructed with a high-density part (32;40) that extend lengthwise of the heel-toe axis and is either bonded to the underside of a lower-density part (31), or forms both an upstanding front flange (43) and a rear body-section (41) of larger mass than, and spaced from, the flange (43).

Putter-Heads

5   This invention relates to putter-heads.

In putting a golf ball, it is desirable to impart forward
rolling spin or topspin to the ball during the putting
stroke.   Topspin reduces ball skid on the putting surface
10   and helps to initiate pure rolling motion, and it one of
the objects of the present invention to provide an
improved putter-head for imparting topspin to a golf ball
on impact.

15   According to the present invention there is provided a
putter-head having a centre of mass located at a distance
p millimetres behind its impact-face at a height h_c
millimetres above the bottom of the head, a moment of
inertia I kilogrammes-millimetres^2 about the vertical axis
20   through the centre of mass, a mass of M kilogrammes and a
radius of gyration of K millimetres about the heel-toe
axis of the head through the centre of mass, wherein:

(a) p/I is not more than 0.18;

25

(b) h_c is less than $[12 - p \times sin(\alpha_{12})]$

where α_{12} is the loft angle at a height of 12
millimetres above the bottom of the head; and

30

(c)   a parameter G defined by:

$$G = p + (3.2 + 70 \times M) \times K^2/p$$

35   has a value less than 350.

The combination of features (a) to (c) of the putter-head according to the invention has been found to endow it with advantageous characteristics that are not achieved with known forms of putter-head. More particularly, the spacing of the centre of mass behind the impact-face and its height above the bottom of the head, together with the moment of inertia of the head about the vertical axis through the centre of mass, and the radius of gyration about the heel-toe axis, and the inter-relationship between them, have been identified as being significant for achieving enhanced putting characteristics. A selection is made of practical ranges of the parameters involved, towards achieving effective design principles that can be readily implemented to give topspin advantageously, without undesirably affecting other characteristics.

Certain preferences within the selection have been identified according to the invention, that lead to further improvement of the putting characteristics as compared with putter-heads of the prior art. In particular, the value of the parameter G is preferably less than 250, or more preferably less than 170, and the height h_c is preferably not more than 8.5 millimetres, or more preferably not more than 7 millimetres.

The location of attachment of the putter-shaft to the putter-head has been found to have a significant effect on putting characteristics of the head. In particular, ratios d_1/K and d_2/K, relating respectively the horizontal offset d_1 millimetres of the attachment from the said heel-toe axis, and its vertical offset d_2 millimetres above that axis, to the radius of gyration K, are relevant. Either or, desirably, both may have a value less than 1.0, or more preferably, less than 0.33. The horizontal offset d_1 may in particular have a value that is less than the radius r (in millimetres) of the putter-

shaft, and may indeed be zero, and the vertical offset d_2 may be negative. More especially, the spacing of the attachment from the centre of mass may with advantage be no more than K millimetres, or even r millimetres.

The putter-head may be such that either or both of the functions D_5 and D_{17} defined by:

$$D_5 = [(3.2 + 70 \times M) \times K^2 + p^2] \times [h_M - 5 + p \times \sin(\alpha_5)]^{-2}$$

$$D_{17} = [(3.2 + 70 \times M) \times K^2 + p^2] \times [h_M - 17 + p \times \sin(\alpha_{17})]^{-2}$$

has a value more than 37 (or preferably not less than 60, or more preferably, 120), where the height h_M is given by:

$$h_M = h_c + p \times [0.12 + \sin(\alpha_M)],$$

and α_5, α_{17} and α_M are the loft angles of the impact-face at heights of 5, 17 and h_M millimetres respectively, above the bottom of the head.

Furthermore, the impact-face of the putter-head of the invention may be a flat surface throughout, or may have upper and lower sections that are contiguous with, and merge smoothly into, one another, the upper section being a flat surface and the lower section having the form of part of the surface of a cylinder that has its axis parallel to the heel-toe axis of the putter-head. In this latter case, or more generally, the impact-face may comply with the following function involving the height h_i (millimetres above the bottom of the head) where impact takes place, and the loft α_i there, namely:

$$h_i - p \times \sin(\alpha_i)$$

is more than the height h_c.

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The putter-head may comprise two parts a first of which
is of high-density material and the second of which is of
a lower-density material, the two parts being bonded
together with the first part under the second part or
located low down within it. Alternatively, the putter-
head may be of metal or high-density composite having an
upstanding front flange and a rear body-portion spaced
from the flange, wherein the rear body-portion is of
larger mass than the flange and extends beyond it in
either direction lengthwise of the heel-toe axis.

Putter-heads in accordance with the present invention
will now be described, by way of example, with reference
to the accompanying drawings, in which:

Figure 1 is a front elevation of part of a putter
incorporating a first putter-head according to the
invention;

Figure 2 is a sectional side-elevation of the putter-head
of Figure 1, shown together with the outline of a golf
ball on a putting surface;

Figure 3 is illustrative in plan view of a base part of
the putter-head of Figure 1;

Figure 4 illustrates in exaggerated form deformation of a
shaft of a putter during impact of the putter-head with a
ball;

Figure 5 illustrates in exaggerated form at (a) to (c)
three cases of deformation of a putter-shaft that are
referred to herein by way of explanation of features of a
putter-head according to the present invention;

Figures 6 to 9 are, respectively, a plan, a front
elevation, a sectional side-elevation and a perspective

view of another putter-head according to the invention,
the section of Figure 8 being taken on the line VIII-VIII
of Figure 6;

5   Figures 10 to 12 are graphs illustrative of
        characteristics referred to by way of explanation and
        description of features of putter-heads according to the
        present invention; and

10   Figures 13 and 14 are a plan view and a sectional side-
        elevation, respectively of a further putter-head
        according to the invention the section of Figure 14 being
        taken on the line XIV-XIV of Figure 13.

15   Referring to Figures 1 and 2, the putter-head 1, which is
        attached near its heel 2 to a putter-shaft 3, comprises a
        substantially flat-topped base 4, a bumper 5 bonded
        firmly to the base 4 and having an upstanding forward
        flange 6, and an element 7 that is inset in, and bonded
20   to, the front of the flange 6 to provide the impact-face
        8 of the head 1. The base 4 extends the length of the
        head 1 with a curved bottom or sole 9, to define the toe
        10 of the head 1 as well as its heel 2.

25   In practice there may be departure from the somewhat
        strictly-rectangular configuration shown for the base 4,
        to incorporate stylistic features, angled surfaces and
        rounded edges. In order to conform to the Rules of Golf,
        the putter head of Figures 1 and 2 should have only one
30   surface, namely impact-face 8, that can be used as an
        impact-face; the opposite, rear face and the toe and heel
        ends should thus contain features which prevent them from
        being usable in this regard.

35   As shown most clearly by Figures 2 and 3, material is
        removed from the top of the base 4 to leave a semi-
        cylindrical recess 11 located symmetrically between the

heel 2 and toe 10. The portion 12 of the bumper 5
located behind the flange 6 fits closely into the recess
11, strengthening the bond with the base 4. The element
7 is bonded to the bumper 5 inset into the front of the
5   flange 6, so as to be located forwardly (by several
millimetres) of the base 4.

The base 4 is of metal or other high-density material and
provides a high proportion of the overall mass of the
10   putter-head 1. The bumper 5, in contrast, is of low-
density material so as to have a very low mass, and is
preferably of a material with high modulus-to-density
ratio such as a high strength plastics or a fibre-
reinforced composite. It is preferably significantly
15   harder and more rigid than a golf ball (i.e. harder than
70 Shore D), and is rigidly bonded or otherwise attached
to the base 4. In this manner, the base 4 and bumper 5
form a substantially single rigid body, with negligible
flexibility in the mechanical interface between them.
20
The dimensions of the recess 11 are chosen to optimise
the location of the centre of mass of the head 1 low down
and rearwardly of the flange 6. The removal of material
from the body 4 by way of the recess 11, reduces the mass
25   of the head 1 but also shifts the centre of mass
downwardly and backwardly depending on the depth and
horizontal extent to which the recess 11 is taken. The
shift downwardly and backwardly is accompanied by re-
distribution of the resultant mass outwardly towards the
30   heel 2 and toe 10. This helps to reduce rotation of the
head 1 about its central vertical axis, and therefore to
improve putt accuracy, in circumstances where impact with
the ball is laterally offset from this axis.

35   The bumper 5 is designed for adequate strength but
minimum weight, since its weight has significant
influence on performance. It provides a very

lightweight, rigid interface between the impact-face 8
and the base 4 and experiences negligible deformation
during putting impact; impact deformation that does occur
is limited primarily to the golf ball and/or the impact-
5   face 8. Although the bumper 5, and the impact-face 8
along with it, might be extended so as to be of
comparable length to the base 4, this would add
superfluous weight where it is not wanted.

10   The element 7 is of a material having specific hardness
and/or resilience and/or ball traction properties;
typically it is of a different material from the bumper
5, but instead of being separate from the bumper 5 as in
the present case, may be formed as part of it. The
15   bumper 5 spaces the impact-face 8 of the element 7
several millimetres forwardly of the base 4 to ensure
that there is a large separation between the face 8 and
the centre of mass of the putter-head 1. The front
flange 6 is the highest part of the bumper 5 and is
20   higher than any part of the base 4, and the vertical and
horizontal dimensions of the face 8 allows reliable
contact with a golf ball for the full range of impact
offset-errors encountered during normal play.

25   For the purpose of further description of the present
invention, reference will be made specifically to Figure
2, which shows the head 1 at the instant of impact with a
golf ball 13 resting on a putting surface 14. By way of
illustration, the centre of mass 15 of the head 1 is
30   shown located at a height h_c millimetres above the sole 9
and at a distance p millimetres behind the impact-face 8,
and the centre of impact (a playing variable with random
error) is identified as being at a height h_i millimetres
above the sole 9. The impact-face 8 may be inclined to
35   provide a few degrees (conventionally, +3 degrees) of
loft angle, but it will be assumed initially in the
description below, that the head 1 is moving horizontally

at impact and that the impact-face 8 is (as illustrated) flat with zero loft angle, and therefore vertical at impact.

5   The main effect required of the impact is to launch the golf ball 13 with linear velocity aligned with the line of intended putt. The linear velocity is proportional to the hit velocity of the head 1, and the ball 13 would attain a maximum value of linear velocity v_c with no spin

10   when the impact-face 8 is square to the direction of movement of the head 1 and the centre of mass 15, the centre of mass of the ball 13 and the point of impact are co-linear. However, when the normal to the impact-face 8 at the point of impact is above the centre of mass 15 as

15   in the case represented in Figure 2, the deceleration force on the putter-head 1 due to the inertia of the ball 13, exerts a 'backspin' moment on the head 1 about its centre of mass 15, and this, by means of 'gear-effect', imparts topspin rotation ω on the ball 13. With the

20   vertical offset of the impact from the centre of mass 15, the linear velocity v_c will be less than the maximum; this is similar to the well-known loss of velocity (and distance) experienced when a ball is putted near the heel or toe (horizontally offset) rather than at the centre or

25   'sweet spot'.

It has been found that the position of the borehole 16 (Figure 3) for attachment of the putter-shaft 3 has a strong influence on the putter-head rotation about the

30   heel-toe axis during the very short duration of impact (less than one millisecond). This is especially the case where the moment of inertia about the heel-toe axis is relatively small, which is a necessary condition for imparting significant topspin. A preferred position for

35   the borehole 16 is such that its axis intersects the rotation axis, that is to say, the heel-toe axis 17 (represented in Figure 3) through the putter-head centre

of mass 15.   This minimises the stiffness to rotation
caused by the shaft 3.

Figure 4 illustrates, in exaggerated form, deformation of
a shaft 20 that results from a rotation Φ radians where
the shaft attachment 21 is offset horizontally by
distance d_1 from the heel-toe axis 22 through the centre
of mass of the putter-head; the un-deformed tubular shaft
20' is indicated in dotted line while the deformed shaft
20 is shown in solid line.   There are two deformation
components that oppose rotation about the heel-toe axis
22, namely axial compression of the shaft by amount $d\Phi$
and bending through angle Φ.   Deflection forces along the
offset direction also occur, but these can be ignored, as
they do not significantly affect rotation.   The force
required to compress the shaft has moment M_1 about the
heel-toe axis 22 and the couple required to bend it has
moment M_2.   Applying standard formulae (see for example,
Gere, J. M. 2001. *Mechanics of Materials*, Pacific Grove,
USA: Brooks/Cole):

$$M_1 = E \times A \times (d\Phi/L) \times d \qquad \ldots (1)$$

$$M_2 = (E \times I_X \times \Phi)/L \qquad \ldots (2)$$

where: E is Young's modulus of the shaft;
          A is the cross-sectional area of the shaft;
          I_X is the second moment of area of the shaft
          about its bending axis; and
          L is the effective length of the shaft during
          impact.

Further, if the shaft has radius r, wall thickness t and
that $r \gg t$ (which is usually the case), then:

$$M_1/M_2 = 2 \times (d_1/r)^2 \qquad \ldots (3)$$

10

Equation (3) demonstrates that the rotational stiffness
is strongly dependant on offset d_l and can be minimised by
making d_l zero (when no direct axial compression or
tension occurs due to rotation about the heel-toe axis).
As the offset d_l increases above r the stiffness increases
rapidly, so there is advantage if d_l is less than r.

Equations (1) to (3) also show that non-standard shafts
could reduce rotational stiffness. For $t \ll r$, the
second moment of area about a bending axis increases as r^3
but the cross-sectional area increases as r, so
increasing r and t, while decreasing E (for example,
replacing steel with an engineering plastic) can provide
a shaft with the same flexural stiffness as a standard
shaft but much less axial stiffness. This reduces
rotational stiffness about the heel-toe axis when it is
necessary to have $d_l > r$. In practice, shaft diameters of
10 to 20 millimetres or greater (compared to 9.4
millimetres in a standard shaft) can be provided using
low modulus material to provide a shaft with ample
strength and durability, but with much reduced stiffness.

With steel putter-shafts the radius and/or wall thickness
of the shaft tip can be reduced. This allows for the
fact that standard steel putter-shafts with diameter 9.4
millimetres have much higher strength and stiffness than
necessary, with greater flexural stiffness than driver
shafts, which are subjected to much higher stress. Thus,
steel or other alloy putter-shafts with small, non-
standard shaft-tip diameters are usefully employed.

Further reduction in torque stiffness can be provided by
arranging that the end of the shaft attaches to the
putter-head at, or more preferably below, the heel-toe
axis through the putter-head centre of mass. This is
illustrated by reference to Figure 5 which shows in

exaggerated form at (a) to (c) three cases of deformation
of a shaft 24, as follows:

(a)   In this case the shaft 24 is considered
unattached to its putter-head, and subject to a force-
couple F1-F1 applied to its free, attachment end 25,
causing it to bend and rotate through an angle ϕ anti-
clockwise. In the absence of any other force, this
would also displace the end 25 to the right, but
lateral force F2 maintains the end 25 in line with the
un-deformed shaft 24'. Due to the finite deformation
curvature, the shaft end 25 does not extend to the
full length of the un-deformed shaft 24'.

(b)   In the second case, the shaft 24 is attached at
its end 25 to a putter-head (not shown) and so
provides reactive forces that oppose anti-clockwise
rotation of the putter-head through angle ϕ about the
heel-toe axis 26 through the centre of mass of the
putter-head. In this case the longitudinal axis of
the un-deformed shaft 24' intersects with heel-toe
axis 26 and the shaft end 25 is above the axis 26.
The reactive forces comprise a clockwise force-couple
F3-F3, substantially equal but opposite to F1-F1, a
lateral force F4 opposite and greater than F2, and a
tension force F5 which arises owing to the elongation
of the shaft resulting from it being pulled down
beyond the extent of the un-deformed shaft 24'.

(c)   In the third case the shaft 24 is similarly
considered attached to a putter-head but in this case
the end 25 of the shaft end 24 is below the heel-toe
axis 26. A clockwise force couple F6-F6 substantially
equal but opposite to F1-F1 opposes rotation, but this
in bending and rotating the shaft-end 25 anti-
clockwise through angle ϕ, deflects it to the right,
which tends to reduce or eliminate lateral deflection

forces.   It also rotates upwards, which tends to
reduce or eliminate shaft axial tension (or
compression) forces that have moments opposing
rotation about the heel-toe axis 26.

5

The above qualitative analysis with reference to (a) to
(c) of figure 5 shows that significantly less rotational
stiffness occurs when the shaft is attached below the
heel-toe axis rather than above.

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In practice, attaching the end of the shaft below the
heel-toe axis is difficult with conventional means;
typically an epoxy adhesive joint is used with the bonded
section of the shaft extends 10 millimetres depth or more

15   into the putter-head. Thus, implementation will require
development of new attachment means where only a few
millimetres of the shaft end is needed to make a reliable
join.

20   It is found that minimising the torque stiffness also
advantageously modifies the acoustic and vibration
characteristics at impact. In this respect, it is also
advantageous to arrange that the borehole or other means
of shaft attachment is not only close to the heel-toe

25   axis as described above, but positioned at, or close to,
the centre of mass.

Other means of reducing the torque stiffness due to shaft
attachment can be provided, including special low-

30   stiffness shaft or shaft-coupling arrangements. A hosel
extension or neck can be provided between the putter-head
and the shaft-attachment point with small and elongate
section to reduce torque stiffness about the heel-toe
axis but maintain adequate strength and robustness.

35   Traditionally, an adhesive is used to bond the shaft end
into the borehole of the putter-head, so the resilience
and thickness of the adhesive material can be designed to

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allow higher compliance, without compromising the
stability and ruggedness of the bond.

It is established teaching that the head of a golf club
5   (including that of a putter) behaves as a free body
during impact. That is, during the very brief time of
contact (less than one millisecond), the shaft has
negligible influence on the outcome of the impact; see
for example: Cochran, A. and Stobbs, J. 1968. *Search for*
10   *the Perfect Swing*, Chicago: Triumph Books, p. 147. It is
thus known that the outcome of a golf shot (including a
putt) can be analysed as a case of eccentric, oblique
impact in a two-body system comprising the ball and club-
head only. From this, exact equations can be derived
15   that predict the launch velocity and spin components of a
golf ball. These equations give accurate prediction of
many aspects of club-on-ball collision in golf. For
convenience, we refer to these equations as 'basic impact
equations'.
20

For example, it is well known that the so-called 'sweet
spot' of a putter-head is normally mid-way between the
heel and toe and corresponds almost exactly to the
position of the centre of mass along the heel-toe axis.
25   At the sweet spot, the ball launch velocity as a function
of putter-head swing speed reaches a maximum, no head
rotation from impact occurs and the contact is 'solid'
with minimum vibration and sound - hence the name 'sweet
spot'. This result is exactly as expected from the basic
30   impact equations.

However, applicant's measurements of putter-head impact
characteristics show that whereas the basic impact
equations accurately predict dynamic behaviour for
35   lateral eccentric impacts that cause rotation about the
putter-head vertical axis, the prediction is inaccurate
for vertical eccentric impact.

In vertical eccentric impact (above or below the sweet
spot), the putter-head tends to rotate about the
horizontal heel-toe axis. In this mode, the putter shaft
presents maximum resistance to movement but the putter-
head moment of inertia is a minimum (being especially
small in putter-heads according to the present
invention). Thus, the model of the putter-head as a free
body is least representative for this mode. This gives
rise to significant discrepancies between measured
performance and performance predicted by the basic impact
equations.

By contrast, in lateral eccentric impact, the shaft
presents much lower resistance to movement about the
putter-head vertical axis and, moreover, the moment of
inertia about this axis is almost invariably a maximum
(due to the practice of 'heel-toe weighting' to minimise
putter-head rotation in this mode). Thus, the basic
impact equations provide a much more accurate model for
lateral eccentric impacts and also accurately predict the
effect of direct oblique impact (as distinct from
eccentric impact) since no club-head rotation at impact
is involved and the shaft constraining forces are
negligible.

A theoretical treatment of the ball-on-putter-head impact
taking account of the shaft constraining forces would be
very difficult and complex. In the present context
therefore, the putter-head is considered as a free, rigid
body detached from its shaft during impact, to which the
basic impact equations are applied to predict
performance. From this the maximum gear-effect
attainable is calculated assuming no shaft constraining
forces, and the result is then qualified to take account
of the possible effect of torque stiffness during impact
due to the shaft.

It is to be appreciated that any practical putter-head
with suitable shaft attachment means can provide
substantially all the available gear-effect performance
predicted by the basic impact equations provided the
5   shaft is sufficiently compliant. New shaft types for
putters may be produced to satisfy this special
requirement, but other factors, such as design aesthetics
or user-preferred shaft type and set-up, may dictate the
overall design so that all the available gear-effect
10   performance is not utilised as a compromise between
desired topspin performance and other factors.

The variables (including fixed golf-ball parameters) used
in the basic impact equations comprise the mass and
15   inertia parameters of the golf ball and putter-head, the
ball radius, and the geometry or shape parameters of the
putter impact-face. For the putter-head, the variables
(and preferred units assumed herein) are:

20   M mass (kilogrammes);
     h_c height of centre of mass above the bottom-most
              part of the putter-head (millimetres);
     p distance of centre of mass behind the impact-face
              (millimetres);
25   K radius of gyration for rotation about the
              horizontal heel-toe axis through the centre of
              mass (millimetres);
     α_i the putter face loft at the point of impact,
              taken as positive for upward tilt (degrees);
30   h_i height of impact point measured above the bottom-
              most part of the putter-head (millimetres);
     I moment of inertia about the vertical axis through
              the putter-head centre of mass (kilogrammes-
              millimetres^2);
35

The gear-effect realised with a putter-head is dependent
on the condition that the line of impact (i.e. the line

normal to the impact surfaces at the point of impact) is
offset from the centre of mass of the head. It follows
that the condition for gear-effect in the present
invention is also dependent on the impact-face loft angle
at the point of impact. The offset h between the line of
impact and the centre of mass, is:

$$h = h_i - h_c - p \times sin(\alpha_i) \qquad \ldots(4)$$

To impart topspin on average rather than backspin, the
average value of h must be positive. A golfer of average
skill can execute putts with average impact heights of 12
millimetres or above, so the condition for h positive (on
average) can be met if h_c is less than:

$$12 - p \times sin(\alpha_{12})$$

where α_{12} is the impact-face loft angle at 12 millimetres
height, measured from the bottom of the putter. This
typically corresponds to an impact height on the face of
the putter of about 10 to 11 millimetres, since the
bottom lip of a putter-face is often raised above the
true bottom surface of the putter by 1 to 2 millimetres.
Preferably, having h_c less than 8.5 millimetres, or more
preferably less than 7.0 millimetres, increases the
probability of topspin. Because the putter-shaft mass is
above the putter-head, the shaft coupling will tend to
increase the effective putter-head centre of mass
slightly above the true h_c value and so the transition
from backspin to topspin will occur slightly higher on
the impact-face than predicted by the basic impact
equations.

Equation (4) shows that if:

$$h_i - p \times sin(\alpha_i) > h_c$$

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is true at every point of the impact-face, then topspin
will always be imparted for normal putts.

Loft angles in putters are seldom greater than 5 degrees
5   and more usually 3 degrees or less, so it can be seen
that the third term on the right-hand side of equation
(4), is only significant if p is large as in accordance
with the present invention. The combination of high
gear-effect and its sensitivity to loft angle allows
10   useful modification of loft angle to enhance performance
in putters of the present invention.

To a first approximation, the basic impact equations
predict that the topspin initially increases linearly
15   with both h and p and increases as the inverse of the
putter-head moment of inertia (with radius of gyration K)
about the horizontal heel-toe axis through the putter-
head centre of mass.

20   The equations also show that as p is greatly increased
the spin rate (for a given h) reaches a maximum and
thereafter reduces, but this only occurs with unusually
large p, so for most practical putter-heads it is safe to
assume that increasing p increases the available topspin
25   performance. Where the shaft attachment is positioned
close to the impact-face of a putter, the effective value
of p is likely to be less than its true value.

A direct result of increasing p is that sidespin from
30   lateral eccentric impacts also increases. That is, when
the impact point is offset from the sweet spot towards
the heel or toe, an increased value of p gives rise to
increased sidespin (all other factors being equal). The
imparted sidespin is believed to have negligible
35   influence on the direction of the putt (see Cochran, A.
and Stobbs, J. 1968. *Search for the Perfect Swing*,
Chicago: Triumph Books, p. 131), but the basic impact

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equations predict that a sideways component of launch
velocity proportional to the sidespin magnitude is
generated, which give rise to directional errors. This
result has been verified by measurement and shown to be
in close agreement with errors predicted by the basic
impact equations. In this regard, it is an aim of the
present invention to limit directional errors by
providing sufficiently large values of I in putter-heads
according to the invention, so that launch angle errors
due to lateral impact offsets of ±12.7 millimetres (i.e.
±0.5 inch) are not more than ±1.6 degrees. In golfing
terms, this corresponds to just sinking a six-foot putt
providing all other aspects of the putt are perfect. A
closely equivalent criterion (which derives from the
basic impact equations) is that the ratio p/I should be
less than 0.18.

Since topspin increases as the inverse of moment of
inertia about the heel-toe axis, limiting this moment of
inertia is another aim of the present invention. This
involves selecting the overall putter-head mass and
controlling the distribution of this mass about the heel-
toe axis. Putter-heads are commonly made with mass in
the range 0.25 kilogrammes to 0.45 kilogrammes but a
narrower range of about 0.3 to 0.35 kilogrammes is
preferred by many manufacturers. We thus see that the
mass of a putter-head is traditionally kept within fairly
narrow limits, presumably to reflect players'
preferences. Therefore, control of the moment of inertia
plays an important part in the design of putter-heads
according to the present invention. Moment of inertia is
proportional to the square of radius of gyration, so
small changes in K can significantly alter the topspin
performance. The applicant has found that the position
of the shaft attachment can alter the effective value of
K and this effect is seen as the most significant in

regards to the problem of torque stiffness due to shaft
attachment.

It has been proved experimentally that with both d_1 (the
5   horizontal offset between the shaft attachment axis and
the heel-toe axis) and d_2 (the vertical offset between the
shaft point of attachment and the heel-toe axis) nearly
zero, the performance of prototype putters according to
the invention closely agrees with the performance
10   predicted by basic impact equations, whereas increasing
either d_1 or d_2 reduces the imparted topspin and also
reduces the variation in launch velocity as a function of
impact height. Thus, there is empirical evidence that if
either d_1 or d_2 is greater than zero the effective radius
15   of gyration K_e is greater than the basic putter-head
radius of gyration K (both measured about the heel-toe
axis through the putter-head centre of mass). It follows
that the ratios d_1/K and d_2/K are important design
factors. It is considered that d_1/K should be less than
20   +1.0 or more preferably, less than +0.33 and similarly,
d_2/K should be less than +1.0 or more preferably, less
than +0.33. However other design considerations may
determine that one or both of these ratios is greater
than +1.0.
25

A further advantage of positioning the shaft coupling
close to the centre of mass is that shaft vibrations due
to eccentric impact are minimised. In this respect, it
is advantageous that the axis of the shaft attachment
30   means passes close to the putter-head centre of mass (as
distinct from the heel-toe axis through this centre).
Some experimental evidence indicates that this
arrangement is also best for ensuring that the assembled
putter advantageously behaves most closely to the model
35   predicted by the basic impact equations. It is thus
preferable that the axis of the shaft attachment means is
offset by less than K millimetres, or more preferably not

20

more than the putter-shaft radius r millimetres, from the
putter-head centre of mass, measured in any direction.

A putter-head in accordance with the invention, of
'mallet' style as distinct from the 'blade' style of the
putter-head of Figures 1 to 3, will now be described with
reference to Figures 6 to 9.

Referring to Figures 6 to 9, the putter-head 30 in this
case involves a substantially rigid, low-density upper
casing 31. An element 32 (see Figure 8) to give mass is
bonded, over-moulded or otherwise attached to the
underside of the casing 31 to extend from heel 33 to toe
34 of the head 30. Alternatively, the element 32 may be
embedded inside the casing 31 by over-moulding or by
encapsulating between two injection-moulded parts or the
like. In this arrangement the element 32 can
advantageously be made from a high-density relatively-
soft metal (such as lead alloy), and holes provided
through it to assist firm bonding to the casing 32.

For cosmetic purposes, the casing 31 may be transparent
or translucent and may be colour tinted or clear, with
the element 32 visible through the casing. In this case,
the element 32 may have a legend, emblem or other
information printed, engraved or cast into it and visible
inside the putter-head 30 through the casing 31; this
allows the bottom surface or sole of the putter-head to
contain such information but still be perfectly smooth.

The attachment socket 35 for the putter-shaft is located
vertically above the heel-toe axis through the centre of
mass of the head 30. More particularly, the socket 35 is
angled so that its axis, and accordingly the longitudinal
axis of the shaft, extends less than K millimetres from
the centre of mass.

The impact-face of the head 30 is provided by an element
36 that is secured to an upstanding flange 37 of the
casing 31; alternatively, the element 36 may be an
integral part of the flange 37. As shown in Figure 8,
5   the impact-face has two sections 38 and 39 that are
contiguous with, and merge smoothly into, one another.
The upper section 38 is flat with positive loft angle α,
whereas the lower section 39 is curved having the form of
part of the external surface of a cylinder of radius R
10   and axis parallel to the heel-toe axis of the head 30;
other surfaces of generally-convex curvature may be used.

The boundary between surfaces 38 and 39 is at height h_α
millimetres. The lofted surface 38 slightly reduces
15   topspin for high values of impact-height h_i but improves
the achieved length of putt by shifting the line of
impact back towards the centre of mass at height h_c.
Here, abundance of topspin is exchanged for slightly less
topspin but improved distance control. Also, the
20   progressively de-lofted surface 39 extends topspin and
putt length at low values of impact-height h_i. The line
of impact is raised relative to the centre of mass and
negative oblique impact is introduced; both assist
topspin and extend putt distance with low impact-height
25   h_i, the compromise being that negative loft is introduced.

Negative loft occurs only at the lower section 39 of the
impact-face. This is not disadvantageous in practice
since putting styles with high loft at impact tend to
30   result in impacts with low height h_i so that negative loft
is cancelled by the orientation of the putter-head at
impact. Conversely, putting styles with low loft at
impact tend to result in impacts with high values of
height h_i where the positive loft of the putter and/or
35   high topspin helps to lift the ball at impact.

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The degree of imparted topspin (or backspin) from a
putter impact is conveniently quantified in terms of the
ratio (namely, S per cent) of the ball peripheral
velocity due to spin to its linear velocity (that is, the
5   translational velocity of the ball centre). From the
basic impact equations, S can be approximated as two
independent terms: one linearly proportional to h
(defined in equation (4) above) and the other linearly
proportional to the obliqueness angle of the impact. The
10   obliqueness angle is dependent on the putter-face loft
angle at impact (α_i) and also on the putting style
(namely, whether the style is 'pendulum swing style' or
swung with the putter shaft tilted forwards or backwards
at impact). In putters according to the invention, the
15   component of S due to oblique impact is very small
compared to the gear-effect (eccentric impact) component.

The function dS/dh is the rate of change of imparted spin
as a function of h and is very nearly constant for any
20   given putter-head with given values of M, K and p, and
provides an important measure of putter-head performance.
Figure 10 shows curves 1 to 6 plotted for dS/dh (in
percent per millimetre) as a function of p for various
values of K and M identified in the following Table I.
25

Table I

Curve	K	M	$M \times K^2$
1	8.4	0.25	17.6
2	8.4	0.35	24.7
3	11.0	0.25	30.3
4	11.0	0.35	42.4
5	15.1	0.25	57.0
6	15.1	0.35	79.8

Curves 1 to 6 show that for a typical range of putter-head mass, the spin rate decreases with K and M and is particularly sensitive to K. The moment of inertia of the putter-head about the heel-toe axis through the centre of mass is equal to $(M \times K^2)$ and this is evaluated in the fourth column of Table 1. From this, it can be seen that spin rate is approximately inversely proportional to the heel-toe axis moment of inertia.

Also, for any given value of heel-toe axis moment of inertia, a value of p equal to about $[8.9 \times K \times M^{1/2}]$ gives the maximum value for the constant dS/dh. However, these values of p are very difficult to implement. For example, with K equal to 14 millimetres, a putter-head of 0.3 kilogrammes requires a value for p of about 70 millimetres, which results in a very large and cumbersome putter-head. On the other hand, small values of K such as 8 millimetres can only be achieved in putter-heads of normal length and mass by using very expensive materials such as tungsten alloys, combined with low density, high modulus composites. Even then, attaining maximum dS/dh is very difficult.

For convenience, a function G which provides a measure of the dS/dh characteristic of a putter-head is defined as:

$$G = p + (3.2 + 70 \times M) \times K^2/p \qquad \ldots(5)$$

In prior art, typical values for K are 11 to 12 for blade style putters, increasing to 14 to 17 for mallet styles, with corresponding p values of about 8 to 10 (blade style) increasing to 14 to 18 (mallet style). Thus, the value of G in the prior art is normally greater or much greater than 350. To allow enhanced topspin in putter-heads according to the invention, the value of G should be less than 350. For preference G should be less than 250, or more preferably less than 170.

24

It has been found that a putter-head design with
exceptionally high topspin can result in severe loss of
linear velocity and consequently, loss of putt distance.
It is thus desirable to calculate the variation in putt
5   length as a function of launch velocity and imparted
topspin variations, and use this information to modify,
if necessary, putter-head parameters so as to obtain
satisfactory putt distance performance.   The theory of
spherically symmetrical balls sliding and/or rolling on a
10   flat uniform surface is well documented.   Thus, exact
equations can be derived predicting the initial linear
deceleration and accompanying rotational acceleration due
to sliding friction and, once pure rolling motion is
achieved, linear deceleration by rolling friction that
15   eventually slows the ball to standstill.

In Figure 11 relative putt distance PD (with zero
corresponding to longest distance) and imparted spin IS
for a possible design of putter-head having the
20   parameters of Table II are plotted as a function of
impact height h_i.

Table II

M	0.3
K	8
p	10
h_c	6
α	0
h_α	0
R	-

Figure 11 shows that this combination of parameters gives
excellent topspin (with $G = 165$) but the relative putt

distance falls off very severely above the mid-height
impact region, reducing to -40% at 20 millimetres. This
would be unsatisfactory for even the least discerning
player so a balance is required between high topspin
5   characteristics and putt-length characteristics. It is
desirable to select parameters to ensure that relative
putt distance is within acceptable limits over the full
range of impact heights.

10   A standard golf ball radius is only 21.3 millimetres, so
a possible putter impact height of 20 millimetres allows
a very small clearance above ground to avoid dragging
effects of the turf. With impact height of 2 millimetres
or less, the ball is struck very near the bottom lip of
15   the impact-face, where impact consistency becomes
unreliable and launch elevation becomes increasingly
negative. There is thus a possible range of about 2 to
20 millimetres, but in practice impact height will rarely
exceed limits of between 5 to 17 millimetres and will
20   average around 10 to 12 millimetres. It is preferable to
ensure that distance loss relative to the peak distance
achieved (for any given putt strength) is not more than
15%. In this regard, it is useful to define the
following functions:
25

$$D_5 = [(3.2 + 70 \times M) \times K^2 + p^2] \times [h_M - 5 + p \times sin(\alpha_5)]^{-2}$$
$$\quad \ldots (6)$$

$$D_{17} = [(3.2 + 70 \times M) \times K^2 + p^2] \times [h_M - 17 + p \times sin(\alpha_{17})]^{-2}$$
30     $$\quad \ldots (7)$$

where:

$$h_M = h_c + p \times [0.12 + sin(\alpha_M)] \quad \ldots (8)$$

35   In the above, h_M and α_M are the impact height and loft
where maximum length is achieved for a given putt
strength. Due to topspin assistance, h_M is higher than

curve B represents the condition in which the values of D_5 and D_{17} are both 60 for typical values of h_M, α_5 and α_{17}. Curve C passes through the points in the dS/dh curves where the magnitude is 95% of peak value, which is taken as a practical limit of p. This provides nearly maximum gear-effect sensitivity for a given K and M combination, but with values of p that are relatively easily implemented. However, larger values of p may be used if required.

Figure 12 shows the topspin and distance characteristics for three putter-heads, namely, two heads identified individually as Head 1 and Head 2, according to the present invention, and a third head according to the prior art. The parameters of the three heads are set out in Table III.

Table III

	Head 1	Head 2	Prior Art
M	0.32	0.30	0.328
K	13.1	10.0	25
p	36	33	30
h_c	6.8	6.0	16
α	0.0	+1.0	+3.0
h_α	0	15	0
R	–	115	–

Head 1 is based on the putter-head of Figures 6 to 9 with a silicon brass mass element (density 8.5 g cm^{-3}) and glass reinforced nylon upper casing (density 1.35 g cm^{-3}). Head 2 is a putter-head designed to give exceptionally high topspin characteristics, using a tungsten or

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tungsten alloy mass element (density circa 18.0 g cm^{-3}).
The prior-art head is a known implementation of a mallet
style putter-head with mass distribution intended to
reduce initial skidding on a putt (by reducing imparted
5   backspin).

In Figure 12, the X-axis gives the height h_i on the putter
face (measured from the extreme bottom of the putter-
head) of impact with the ball, and the Y-axis gives the
10   percentage variation. Trace A shows topspin for Head 1
and trace B shows relative putt distance for constant
putter-head impact velocity. From this, it can be seen
that 5% to 8% topspin are obtained for impacts in the
range 10 to 12 millimetres, whereas topspin of 15% or
15   more can be achieved by controlling the putter-head to
strike the ball near the bottom of the swing with the
sole of the putter fairly close to the putting surface.
Trace B shows that the variation in distance is closely
controlled in Head 1 and, advantageously, approximately
20   symmetric about 11 millimetres impact height. In the
impact height range 5 to 17 millimetres the distance
decrement is less than 4%.

Traces C and D of Figure 12 show topspin and relative
25   distance for Head 2. Here very high topspin is generated
throughout the normal impact height range, but distance
loss increases slightly at high impact heights. A
special feature of Head 2 is that the impact-face is
profiled with a loft of +1 degree above 15 millimetres
30   height, decreasing at a uniform rate below this height to
-4 degrees at 5 millimetres height. Despite this
negative loft, the putter still imparts lift (that is to
say, positive elevation ball trajectory). For impacts
above 9 millimetres, the gear-effect is more than
35   sufficient to impart upward velocity greater than the
component of downward velocity due to negative loft.
Impacts below 9 millimetres height only arise if the

putter-head is raised high off the putting surface at the
bottom of a pendulum swing (that is, the shot is badly
executed) or, more preferably, if the putter-head is on
an upward trajectory and this itself imparts lift to the
5   ball at impact.

Traces E and F of Figure 12 show spin and relative
distance for a prior-art putter-head. With this head
function $G = 575$, which provides moderate dS/dh, but the
10   high h_c combined with positive loft results in backspin
increasing significantly with low impact-height and this
in turn results in (the predicted) loss of distance at
low impact height. In practice, the shaft coupling of
this head would tend to improve putt-length variation but
15   slightly further increase the sweet-spot height.

Because imparted topspin in the present invention relies
on impacts being off-centre from the 'sweet spot', levels
of head-vibration can be greater than that obtaining in a
20   conventional putter where sweet-spot impact is expected.
The known method of reducing such vibration is to clad
the metal or other low-loss parts with high-loss
materials. Advantageously, the major part of the putter-
head according to the invention can be made from a high-
25   loss material such as a polymer or composite (Ashby, M.
A. 1992. *Materials Selection in Mechanical Design*, 2nd
ed., Oxford: Butterworth-Heinemann, pp. 46-48). If
necessary, cavities or recesses in the putter-head can be
provided and filled with high loss materials, provided
30   these do not reduce the overall rigidity of the putter-
head. Other methods for low-frequency vibration control
include filling the shaft with vibration dampening
material such as granular material sold under the Trade
Mark LODENGRAF.
35

Referring now to Figures 13 and 14, a putter-head body 40
is fabricated from a single material such as metal alloy

or high density composite. With a metal-only body, the
putter-head can advantageously be cast to allow high
volume, low cost manufacture. In this form, the body 40
is preferably made of a high loss alloy such as cast

5   iron, low-carbon steel, zinc alloy or manganese-copper
alloy.

The greater part of the head-mass is provided by the
rear-body section 41 which preferably extends, heel to

10   toe, at least 120 millimetres or significantly more (so
as to be longer than an average putter-head). This helps
to reduce the moment of inertia about the heel-toe axis
and advantageously increases the moment of inertia about
the central vertical axis. The provision of a chevron-

15   shaped cut-away 42 between the rear-body section 41 and
the front flange 43 with its impact-face 44, further
reduces the heel-toe moment of inertia.

The cut-away 42 also provides an alignment aid when

20   addressing a ball during play. Small differences in
alignment relative to the intended line of putt are shown
up by the obtuse angle 45. In an alternative
arrangement, the cut-away 42 is replaced by a thin plate
section and the chevron-shaped feature is highlighted

25   with a contrasting-colour paint. In another arrangement,
a bridge part can be provided across the centre, so
dividing the cut-away into two symmetrical apertures.

In this embodiment of the invention, the putter-shaft

30   (not shown) is attached at or close to the centre of mass
of the putter-head by a re-entrant 'over-hosel'
arrangement (best seen in Figure 14). More particularly,
a tapered stub 46 projects upwardly coaxially within a
cylindrical recess 47 in the rear-body section 41 of the

35   head 40. The hollow end of the putter-shaft is fitted
onto the stub 46 leaving space between it and the
cylindrical wall of the recess 47. This space is filled

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with a high-toughness, flexible adhesive that is also
used to secure the shaft to the stub 46. so as to form a
strong but compliant bonding of the shaft to the head 40.
The adhesive is preferably coloured to enhance the
5   appearance of the join.

Claims:

1.   A putter-head having a centre of mass located at a distance p millimetres behind its impact-face at a height h_c millimetres above the bottom of the head, a moment of inertia I kilogrammes-millimetres^2 about the vertical axis through the centre of mass, a mass of M kilogrammes and a radius of gyration of K millimetres about the heel-toe axis of the head through the centre of mass, wherein:

(a) p/I is not more than 0.18;

(b) h_c is less than $[12 - p \times sin(\alpha_{12})]$

where α_{12} is the loft angle at a height of 12 millimetres above the bottom of the head; and

(c)   a parameter G defined by:

$$G = p + (3.2 + 70 \times M) \times K^2/p$$

has a value less than 350.

2.   A putter-head according to Claim 1 wherein the value of G is less than 250.

3.   A putter-head according to Claim 2 wherein the value of G is less than 170.

4.   A putter-head according to any one of Claims 1 to 3 wherein height h_c is not more than 8.5 millimetres.

5.   A putter-head according to Claim 2 wherein height h_c is not more than 7 millimetres.

6.   A putter-head according to any one of Claims 1 to 5 wherein the ratio d_1/K is less than 1.0, where d_1 millimetres is the horizontal offset from said heel-toe axis of the axis of attachment of the putter-shaft to the putter-head.

7.   A putter-head according to Claim 6 wherein the ratio d_1/K is less than 0.33.

8.   A putter-head according to Claim 6 or Claim 7 having a putter-shaft of radius r millimetres, wherein d_1 is less than r.

9.   A putter-head according to Claim 6 wherein d_1 is zero

10.   A putter-head according to any one of Claims 1 to 9 wherein the ratio d_2/K is less than 1.0, where d_2 millimetres is the vertical offset above said heel-toe axis of the axis of attachment of the putter-shaft to the putter-head.

11.   A putter-head according to Claim 10 wherein the ratio d_2/K is less than 0.33.

12.   A putter-head according to Claim 10 wherein d_2 is negative.

13.   A putter-head according to any of Claims 1 to 12 wherein the axis of putter-shaft attachment to the putter-head is spaced by less than K millimetres from the centre of mass.

14.   A putter-head according to any of Claims 1 to 13 wherein the axis of putter-shaft attachment to the putter-head is spaced by no more that the radius r millimetres of the putter-shaft from the centre of mass.

15.   A putter-head according to any one of Claims 1 to 14 having impact-face loft angles α_5 and α_M at heights of 5 and h_M millimetres respectively, above the bottom of the head, the height h_M being given by:

$$h_M = h_c + p \times [0.12 + sin(\alpha_M)],$$

wherein a function D_5 defined by:

$$D_5 = [(3.2 + 70 \times M) \times K^2 + p^2] \times [h_M - 5 + p \times sin(\alpha_5)]^{-2}$$

has a value that is more that 37.

16.   A putter-head according to Claim 15 wherein the function D_5 has a value that is not less than 60.

17.   A putter-head according to Claim 15 wherein the function D_5 has a value that is not less than 120.

18.   A putter-head according to any one of Claims 1 to 15 having impact-face loft angles α_{17} and α_M at heights of 17 and h_M millimetres respectively, above the bottom of the head, the height h_M being given by:

$$h_M = h_c + p \times [0.12 + sin(\alpha_M)],$$

wherein a function D_{17} defined by:

$$D_{17} = [(3.2 + 70 \times M) \times K^2 + p^2] \times [h_M - 17 + p \times sin(\alpha_{17})]^{-2}$$

has a value that is more that 37.

19.   A putter-head according to Claim 18 wherein the function D_{17} has a value that is not less than 60.

20.   A putter-head according to Claim 18 wherein the function D_{17} has a value that is not less than 120.

21.   A putter-head according to any one of Claims 1 to 20
wherein the impact-face has upper and lower sections that
are contiguous with, and merge smoothly into, one
another, the upper section being a flat surface and the
lower section having the form of part of the surface of a
cylinder that has its axis parallel to the heel-toe axis
of the putter-head.

22.   A putter-head according to any one of Claims 1 to 21
wherein for impact at any point on the impact-face, the
following function involving the height h_i of that point
above the bottom of the head and the loft α_i of the
impact-face at that point, namely:

$$h_i - p \times sin(\alpha_i)$$

is more than the height h_c.

23.   A putter head according to any one of Claims 1 to 20
wherein the impact-face is a flat surface.

24.   A putter-head according to any one of Claims 1 to 23
comprising two parts a first of which is of high-density
material and the second of which is of a lower-density
material, the two parts being bonded together with the
first part under the second part or located low down
within it.

25.   A putter-head according to any one of Claims 1 to 23
of metal or high-density composite having an upstanding
front flange and a rear body-portion spaced from the
flange, wherein the rear body-portion is of larger mass
than the flange and extends beyond it in either direction
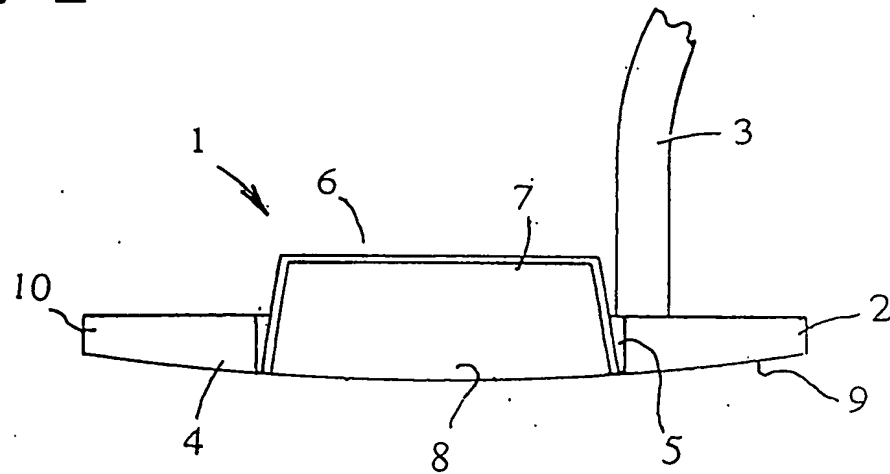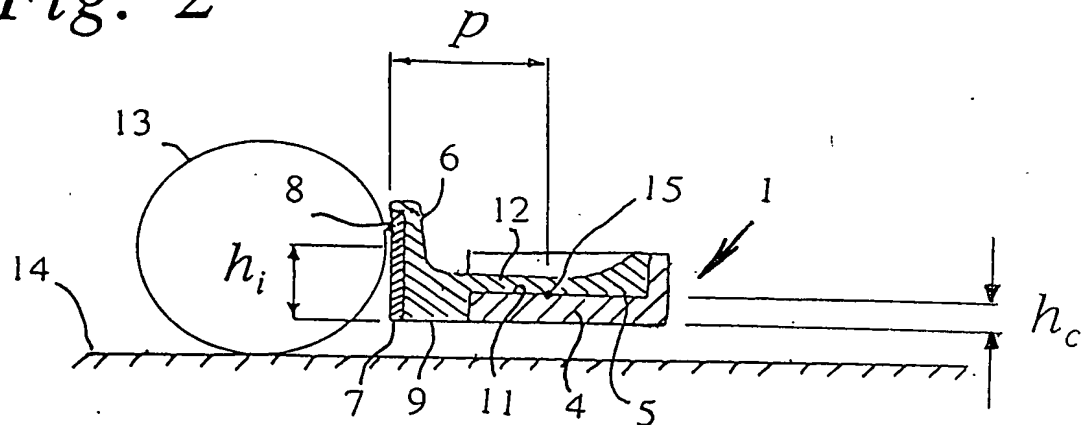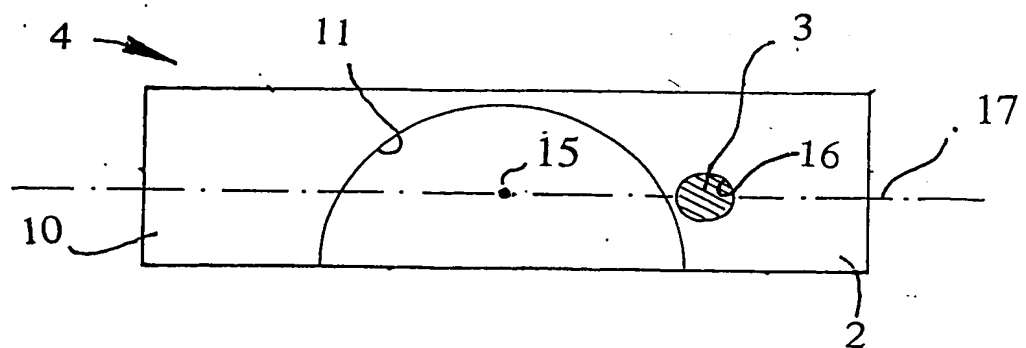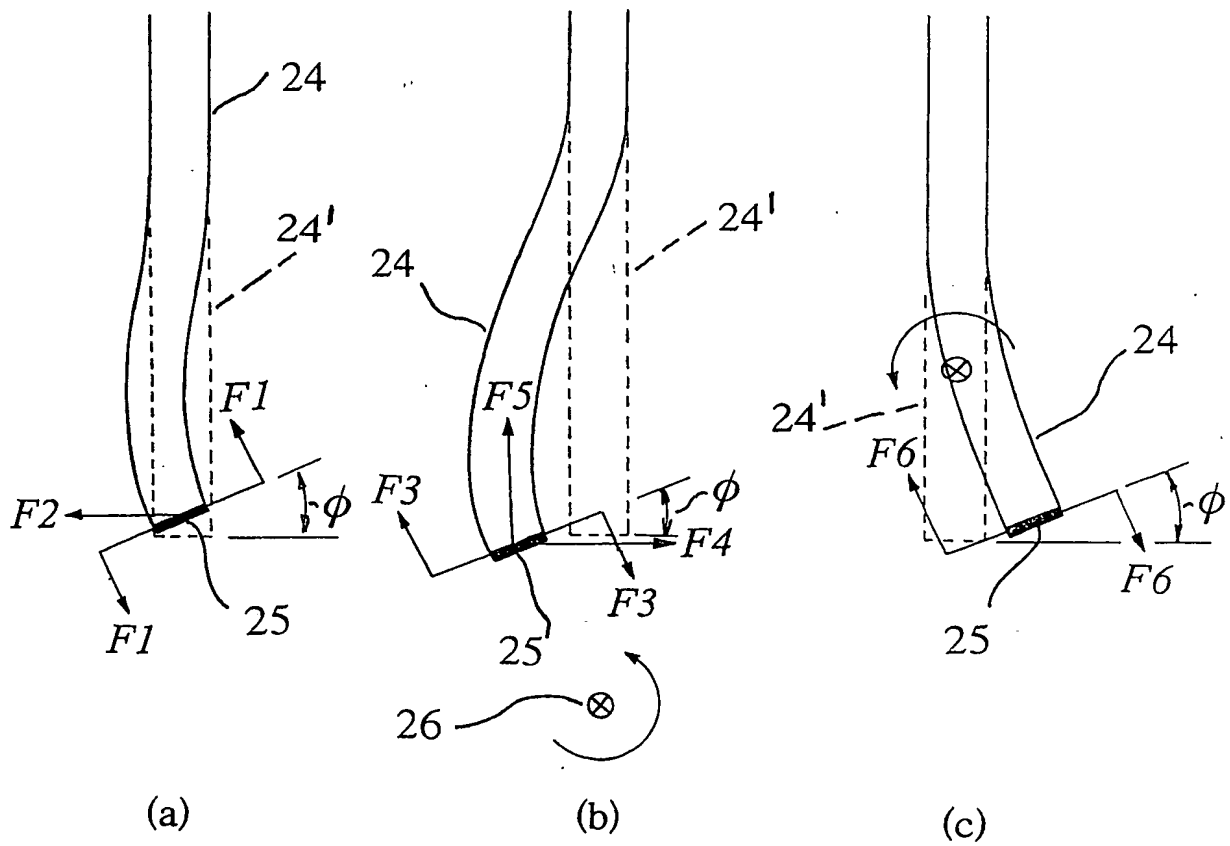lengthwise of said heel-toe axis.

Fig. 1

Fig. 2

Fig.3

Fig. 4

Fig. 5

(a)   (b)   (c)

3/8

Fig.6

Fig.7

Fig.8

Fig.9

Fig. 10

6/8

impact height h_i (mm)

Fig. 11

Fig. 12

XIV

40

41

46   47

42

43

45   44

Fig. 13

46   43   44

47

40

Fig. 14